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The use of attached-sunspaces in retrofitting design: the case of residential buildings in Portugal

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Abstract

This study addresses the energetic performance of an attached-sunspace applied to an existing residential building in Portugal. Four configurations (two attached, one integrated and one partially integrated) are studied in six different climatic zones. In addition other key parameters are considered such as ventilation (with or without natural ventilation), shading devices (one external and two internal configurations), number of glazed surface layers (single glazed and double glazed) and orientation (South, East and West).
The thermal performance analysis, carried out using a dynamic simulation code, proved that energy savings for retrofitting design can be very important and that in climates with warm summers the risk of overheating can be considerably diminished through an accurate analysis based on modeling.

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1. Introduction

The residential sector represents approximately 17% of the final energy consumption in Portugal, with nearly 25% of it being due to air conditioning. Approximately 65% of the residential building stock is built before the

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implementation of the first building code, most of it having a poor energy performance. Therefore, the use of attached-sunspaces in these buildings is very attractive given the good solar potential of the country and economic advantages the systems offers when compared with traditional retrofitting approach based on the use of thermal insulation.

Attached-sunspaces have been used successfully in retrofitting existing buildings with poor energy performance [1] while the thermal performance of sunspaces was investigated by several authors.

Numerical investigations have been conducted by Mihalakakou [2], Bataineh and Fayez [3] and more recently by Oliveti et al. [4]. Both numerical and experimental investigations have been done by Roux et al. [5], Mottard and Fissore [6], Asdrubali et al. [7] and Rempel et al. [8].

Mihalakakou [2] aimed to investigate the influence of a sunspace on the thermal behavior of a building located at different locations throughout Europe. The effects of the sunspace presence on the air temperature of the adjacent building with no air-conditioning were evaluated by a dynamic code that does not consider the directional aspects of the incoming radiation.

Bataineh and Fayez [3] studied the energy potential of a sunspace connected with a living room located in Amman, Jordan. Design variables such as glazed-to-opaque surface area ratio, opaque wall and floor absorption coefficients, number of glass layers and sunspace orientation were studied by numerical means together with night ventilation effects and daytime curtain shading to prevent summer overheating.

Oliveti et al. [4] investigated the solar gains and the operative temperature of sunspaces in free floating conditions (no air conditioning) for the Italian cities of Cosenza, Rome and Milan. Sunspace orientation, the absorption coefficients and heat capacities of the vertical wall and the floor together with ventilation rate and external shading system were studied by means of a dynamic building code.

With regard of the numerical and experimental studies, they report the validity of numerical codes for predicting the thermal performance of sunspaces by comparing the results of dynamic energy modeling with results obtained from testing full-scale experimental buildings considering sensitive analyses [5] and design variables such as long infrared and the distribution of solar radiation in the sunspace [6].

In the numerical and experimental study developed by Asdrubali et al. [7], the effect of a typical solar greenhouse on the energy balance of a residential flat was evaluated during the winter time with analytical and numerical tools for a Umbria Region of Italy. A comparison was made between estimates of energy demand with real energy consumptions of the flat over the heating period. No analysis was provided about the thermal performance of the flat or the sunspace system during cooling season.

In the numerical and experimental study developed by Rempel at al. [8], the energy transfer mechanisms underlying the measured performance of four sunspaces located in Oregon, USA were investigated using a dynamic building code. In the same study, the models were validated by comparison with recorded data of air, mass, globe, and soil temperatures, relative humidity and incident solar radiation.

Overall, these studies show that sunspaces can be an appropriate and effective system all year round if properly designed to take full advantage of local climate and if overheating is addressed by passive means. Although the need for heating is higher than the need for cooling in most of the territory of Portugal, in order to accurately predict the potential influence of various factors upon the thermal performance of a residential building with an attached-sunspace in the present study, a dynamic building simulation code was used [9]. This study is also motivated by the apparent lack of information regarding the potential of use of attached-sunspaces in retrofitting design in Portugal.

2. Methodology

2.1. Case study

Solar energy storage by means of sunspaces is possible to various extents to the existing building stock and consists of attached glass house (new building extension) or glass covering the balconies. The adjacent space constituted in such way acts as a thermal buffer between inside and outside of the building, and as a solar collector when heat is transferred to the living spaces through the masonry common wall. Pre-heated ventilation is also possible when warm air flow into adjoining spaces via openable vents or windows. Operable vents located at the top of the sunspace may also be used in conjunction with shading in order to overcome the overheating problems.

In the present study, four sunspace configurations are studied: two attached, one integrated/embedded and one partially integrated/embedded (Fig. 1). The sunspace, which is south-facing, is located on the main fabric envelope of a building with the geometrical characteristics shown in Fig.1. The north and south boundaries (external envelope) of the flat are made of a single layer of brick masonry (typical for buildings built before the publication of the first building code) with a thermal transmittance U = 1.3 W/m^2. K. Both north and south facing building envelope have single-glazed operable windows with thermal transmittance U = 5.7 W/m^2 K. All other surfaces are considered adiabatic. The height of sunspace are taken to be similar to those of adjacent rooms, H = 2.8 m.

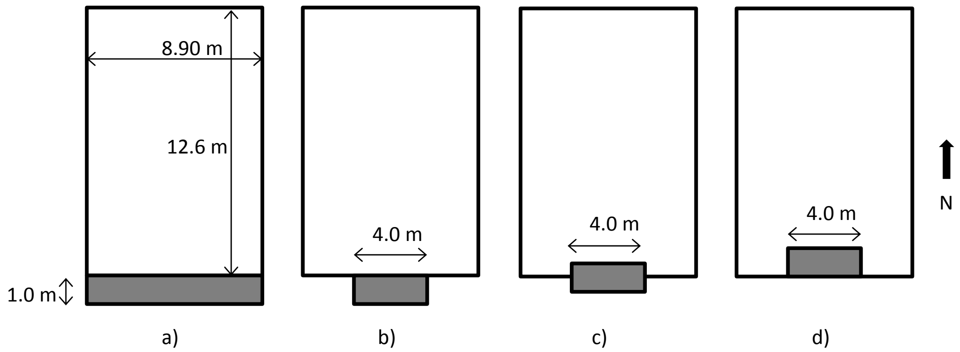

Fig. 1. Building floor dimensions and sunspace configurations: (a) adjacent; (b) adjacent; (c) partially integrated; (d) fully integrated.

2.2. Modeling approach

The main function of sunspaces is to collect solar energy and reduce the need for other energy resources and energy consumption. Taking this into account, in order study to energetic performance of an attached-sunspace applied to an existing residential building in Portugal, simulations have been performed using a dynamic simulation code EnergyPlus [8]. This approach is similar to other studies reported in the literature, where EnergyPlus results have been validated against experimental measurements and proved to be reasonably accurate in estimating the thermal performance of sunspaces [6,8].

The simulations have been performed for a single zone with the sunspace implemented into EnergyPlus as a different thermal zone. All building surfaces were modeled explicitly, including internal partition walls (not shown in Fig. 1).

The thermal behavior of the building model with the sunspace attached was simulated for a whole year, assuming for the calculation of the energy need for heating and cooling set point temperatures of 20 ºC and 25 ºC respectively. Throughout all simulations it was considered a value of internal heat gains and ventilation rate around the year equal to 4W/m^2 and 0.6 h^{-1}, respectively.

Building solar distribution was simulated as “Full-InteriorAndExteriorWithReflections”, in which beam solar radiation is projected through glazing to the correct zone surface, and absorbed or reflected accordingly. For the external and internal convective coefficient ‘‘TARP” model was used [9], which splits the convection into forced and natural components.

2.3. Design variables

In order to predict the potential influence of various factors upon the thermal performance of the sunspace, for all configurations shown in Fig. 1, a sensitivity analysis was conducted for six representative cities of Portugal on the following variables:

- Natural ventilation of the sunspace (with and without operable windows)
- Shading devices (with and without; exterior and interior; high reflectance and low reflectance)

- Number of glazed surface layers (single and double)
- Opaque wall at balcony level (with and without)
- Orientation (South, West and East)

The main climatic features of the six cities under analysis are shown in Table 1, where, in addition of the heating degree days and conventional heating period, the mean daily thermal amplitude of each location is given [10]. The mean daily thermal amplitude is calculated as the difference between the minimum and the maximum temperature for each day averaged for the hottest month of the cooling season.

Table 1. Main climatic features of the six cities under analysis

Location	Heating degree days (*℃ days*)	Conventional heating period (*months*)	Mean daily thermal amplitude (*℃*)
Faro	1060	4.3	12
Lisboa	1190	5.3	11
Évora	1390	5.7	17
Coimbra	1460	6.0	13
Porto	1610	6.7	9
Bragança	2850	8.0	15

3. Results and discussion

The thermal performance of the sunspace was therefore evaluated by estimating the energy demand of the building for all combinations of the parameters mentioned above. The comparison of the energy demand values obtained for heating and cooling season and annually in each case, with the corresponding values of the building without the sunspace (taken as reference), has revealed interesting features. Firstly, the most successful combinations for annual energy demand reduction across all six cities have in common south orientation, fully integrated sunspace configuration (Fig. 1), natural ventilation of the sunspace and inner shading devices with high reflectance. For the rest of the design variables it was found that they depend on the climate characteristics (Table 2). For the sites characterized by colder and longer winters (Porto and Bragança) double-glazed sunspaces are more effective in keeping the sunspace warm. In the case of warmer summers sites (Faro), a sunspace with the lower portion of opaque wall (balcony) is more appropriate for reducing the amount of solar energy collected in order to avoid overheating. Regarding the sunspace configurations, the fact that the fully integrated configuration has less glazing surface in contact with exterior is an advantage.

Table 2. Qualitative analysis of the design variables which are most appropriate for energy demand reduction

Location	Configuration (Fig.1)	Glazed surface layers	Opaque wall
Faro	d)	Single	With
Lisboa	d)	Single	Without
Évora	d)	Single	Without
Coimbra	d)	Single	Without
Porto	a) / d)	Double	Without
Bragança	a) / d)	Double	Without

Table 3 shows the energy demand with attached-sunspace relatively to reference case for the most successful combination of design parameters found for each sunspace configuration for each city. As it can be seen, the potential for energy savings in winter can be very important, ranging from 100% in Faro (energy demand for heating is reduced to zero) to 48% in Bragança. Regarding summer thermal behavior one can also note improvements in most of the cases, though the associated savings in this case are substantially lower than the winter savings. One important feature is that during summer, four cities (Évora, Coimbra, Porto, Bragança) are subjected to overheating risk in configuration a (positive values indicate a negative impact as energy demand increases).

These results agree with the literature as to the passive solar heating potential of the sunspaces and as to the importance of adopting appropriate measures for decreasing the overheating risk.

Table 3. Energy needs with attached-sunspace relatively to reference case; negative percentage indicates relative reduction, positive percentage indicates relative increase

Configurations (Fig. 1)	a)	b)	c)	d)
Cities	Winter/Summer/Annual	Winter/Summer/Annual	Winter/Summer/Annual	Winter/Summer/Annual
Faro	-93/-10/-16	-57/-16/-19	-35/-13/-15	-100/-15/-23
Lisboa	-72/-10/-30	-60/-12/-24	-46/-10/-21	-90/-10/-38
Évora	-70/1/-30	-40/-8/-20	-27/-7/-16	-66/-8/-34
Coimbra	-70//5/-35	-43/-9/-24	-32/-7/-20	-68/-9/-40
Porto	-70/28/-53	-45/-3/-35	-32/-1/-26	-66/-4/-55
Bragança	-48/10/-38	-33/-5/-26	-24/-5/-20	-46/-6/-38

Despite of the encouraging results obtained for most of the climatic zones, in practice, the successful implementation of the above strategies is likely to depend also on the user behavior. If the sunspace is seen as an extension of the building, it is often heated in winter and the potential energy savings may change into additional energy use if the existent door to the sunspace is opened to allow some warm air to be delivered to the house. This is an important contribution to the energy performance of the sunspace which can be responsible for a considerable amount of energy savings when compared to the case where the sunspace is not used for supplemental heating [11].

Given that unreliable assumptions may lead to unrealistic results, user behavior should ideally be assessed in performance simulations of buildings that have a known close interaction of the user with the building [12]. User behavior models, however, are difficult to employ as the details of the user interaction with the building are often unavailable or can widely vary [13].

4. Conclusions

A numerical investigation was designed in order to study the energetic performance of an attached-sunspace applied to an existing residential building in Portugal. The analysis, which was based on estimating the energy demand of the building with and without the sunspace for six different climatic sites, has revealed which are the design variables that more significantly impact the thermal behavior and which are the expected amounts of energy savings in each case. Key design include: orientation, sunspace configuration, natural ventilation of the sunspace and position and radiative properties of the shading devices.

In addition to the strategies defined according to climatic features and building geometry and physical characteristics, another fundamental variable which can strongly influence the energy savings is the user behavior which in turn depends on the user availability and knowledge to control the amount of heat to be delivered to the house or to be extracted from the sunspace (by controlling the ventilation openings, the doors and shading devices) according to the appropriate comfort needs and available conditions.

Although the economic advantages of the use of sunspaces in retrofitting over the traditional approaches remains to be demonstrated, it is believed that this paper presents useful insights regarding the strategies and variables which are likely to improve the energy performance attached-sunspaces.

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